
# ACHEMA 2000
# 22. – 27. May 2000
# Frankfurt am Main/Germany

*The opening ceremony of the 26th ACHEMA was performed in the CongressCenter at the Frankfurt Exhibition Grounds. From Monday, May 22, 2000 the gates to the world's biggest chemical engineering Exhibition–Congress and International Meeting on Chemical Engineering, Environmental Protection and Biotechnology was opened to the public for 6 days.*

*The special trend reports of ACHEMA 2000 exibition (no 1–19) were prepared for publication by authorities from DECHEMA. In this and following issues of Chemical Industry Jl. will be presented some of them. In this issue Process Identification, Process Instrumentation and Control, Process Safety, and Plant Engineering Tools are presented as prepared by DECHEMA for the press–information.*

**ACHEMA 2000 – The giant innovation show of process industry**

ACHEMA 2000 is once again set to break all previous records as pointed by Prof. dr G. Kreysa, Chief Executive of DECHEMA e.V.

With 4.144 exhibitors from 48 countries and compared with 1997, the number of exhibitors has risen by 12,1 %. The absolute and the highest increase in the history of ACHEMA of exhibitors amounts to 447. In contrast to former ACHEMA events, the growing number of exhibitors can no longer only be put down to the number of those from abroad. The percentage from abroad rised from 34.2 % to 38,5 %. The figures for foreign exhibitors showed an increase of 23,3 %, while those for German exhibitors 6,3 %. The net exhibition area totals 145,499 square metres, which means an increase of 3.4 % for the first time for several years. Apart from Germany (with 2,584), the five leading countries in terms of exhibitors are Italy (244), Great Britain (226), the USA (194), Switzerland(168), and France (148). The highest growth rates, compared with 1997, have been achieved by the People's Republic of China (with + 533 %), Slovenia (+ 275 %), Taiwan (+ 240 %), India (+ 41 %), the Czech Republic (+ 38 %) and the USA (+ 36 %).

At ACHEMA 2000, all the equipment sectors of the chemical process industry, from research and the laboratory to entire plants, were represented in twelve exhibition groups, the special show on "Synthesis, Screening and Sequencing Machines", and the two cross–sectoral topics: Environmental Protection and Biotechnological Equipment.

For the first time young, research–oriented biotechnology start–up companies, organised in Germany within DECHEMA as the Association of German Biotechnology Companies (VBU) had their own new Biotechnology exhibition group. With 1,537 exhibitors the cross–sectoral topic Environmental Protection was increased by 49% and Biotechnological Equipment with 1,189 exhibitors by 38 %. This facts showed that, even in these two key sectors, ACHEMA has further consolidated its uncontested supremacy.

The primary objective of ACHEMA was to foster the exchange of ideas and experience between manufacturers and users of plant, equipment, components and apparatus. Special emphasis was placed on the presentation of innovations and new developments. The intensive discussions among experts from about 100 different countries stimulated the interdisciplinary exchange of information between science and technology.

The Research and Innovation exhibition group with a total of 251 exhibitors has recorded an increase of 34 % over the last ACHEMA. This exhibition group is a particularly effective instrument for the conversion of research results into industrial applications. Once more, not only university institutes and publicly funded research centres but also private research firms are represented in this group. The voluntary contributions of the exhibitors and visitors to the Max Buchner Research Foundation yield approximately 80 scholarships for basic research annually, which represents a significant contribution by ACHEMA to the promotion of research.

In addition to the Research and Innovation exhibition group, those for Pharmaceutical, Packaging and Storage Techniques, Thermal Processes, Pumps, Compressors, Valves and Fittings, and Materials Technology and Testing have registered double–digit growth rates.

Four podium discussions on topical issues of interest to a broad section of the public aim to improve the acceptance of technology by providing information and by entering into a dialogue with various social groups.

The lecture programme of the International Congress featured 940 contributions (28 % over 1997).

Note: This press release can also be downloaded from the Internet
http://www.dechema.de

Highlights of this congress were the 1st International Symposium on Synthesis, Screening and Sequencing Machines, and the Resources Development Forum which brang together leading representatives of countries that are rich in resources and potential investors from the chemical process industry.

Besides the ACHEMA catalogue and the multimedia information system WOICE of ACHEMA, information on the products and services of the exhibitors was provided by the special Exhibition Guides Environmental Protection and Biotechnological Equipment.

The Electronic Catalogue, intensively used by about 20,000 visitors, was once again available to all who wished to plan their visit to ACHEMA in detail and thus make the best use of their time there. The ACHEMA pages in the Internet have been accessed individually more than 11 million times and have been consulted intensively in almost 250,000 user sessions worldwide averaging 16,5 minutes each.

WOICE of ACHEMA, the World Catalogue of International Chemical Equipment, the multimedia CD–ROM contains information on all the exhibitors at ACHEMA and ACHEMASIA and on 651 additional companies as well as 402 reports from research institutes around the world. WOICE also features detailed technical reports using texts and graphics with audio slide–shows, video sequences und computer animation. This all comes with user–friendly software with patented components especially developed for this CD–ROM and the additional bonus of a four–language scientific dictionary with 12,000 terms. WOICE represents the cutting edge in the presentation of scientific and technical information. Thus the classic discussion close to the real exhibits – the hallmark of ACHEMA – has now been complemented and extended by the ongoing discussion of the virtual exhibits.

Once again, DECHEMA anticipated welcoming around a quarter of a million visitors to ACHEMA (1997, total of 228,416 participants from 100 countries). The ACHEMA Study Courses offered by DECHEMA serve to nurture the scientific and technical talents of the next generation and the continuing education of teachers in the natural sciences. Visitors to ACHEMA are highly qualified professionals. In 1997, 33.8 % of visitors came from abroad, 21 % were scientists and 37 % engineers. Laboratory technicians accounted for 15.7 %.

## PROCESS INTENSIFICATION

### A radical design approach makes production plants smaller, cheaper and safer

The concept of Process Intensification (PI) was born from the recognition that much of the capital cost for a chemical plant is related to the civil engineering structure. With multipliers of two–to–seven times the cost of the individual plant items, significant reductions in capital cost can be achieved by reducing chemical plant size. ACHEMA 2000 showed numerous concepts and solutions for process intensifications.

PI drivers have now grown beyond the initial reduction of "infrastructure" costs. New equipment and processing ideas have led to improved production methods which convert more of the raw material into final product increasing productivity and purity, and thereby reducing downstream processing. Reduced processing time allow the conversion of batch processes to continuous giving significant improvements in safety and continuity of product quality. Environmental benefits arise from reductions in raw material consumption, waste and energy demands.

The fluid dynamics in a chemical process plays many important roles. The first of these is to bring the reagents together, at the molecular scale. Achieving this in a time shorter than the characteristic reaction time ensures that the mixing has little or no influence on the product distribution. The fluid motion also provides the means by which heat can be supplied to or removed from the reaction components. Reaction cannot occur until individual molecules of the reagents are brought together. Only molecular diffusion can accomplish this. However, one can help these encounters to occur by establishing fluid structures at which molecular diffusion becomes significant. Creating these small scale fluid structures is the role of the reactor and the mixing and mass transfer equipment associated with it.

In order to generate and improve mixing or mass transfer the reactor equipment must direct energy in the correct way into the fluid system. In a stirred tank reactor (STR) the energy input clearly comes through the impellor, but this arrangement suffers high energy losses through frictional and other losses. The energy which remains is focused mainly upon the fluid in contact with the impellor. This means that while power inputs at the impellor tip may be very high (1000's W/kg) the majority of the fluid is unaffected and the average power input across the whole tank is low (0.1–1 W/kg). The devices described below, such as rotor–stators, where the proportion of the fluid in contact with the rotor is higher, and static mixers and ejectors where the large amount of energy which can be supplied by pumps goes into the whole of the fluid means very high average power inputs (100W/kg) can be created.

### High Intensity Inline Mixers

Static, or motionless, mixers are perhaps the simplest and most versatile of process intensification equipment with application in reactions where at least one phase is a liquid. They are tube inserts which use the pumping energy/pressure drop to induce mixing and can be roughly divided into three categories:

(1) Turbulent flow mixers that rely on the vortices shed from tabs positioned on the walls of the device.

They promote mixing in an axial direction and so approximate well to plug flow devices;

(2) Laminar flow mixers which physically redistribute, stretch and fold the fluid;

(3) Those used for both regimes.

Ejectors, for gas–liquid contacting, consists of four main sections. A spinner takes the pumped liquid and orientates and stabilizes its flow before it passes through a nozzle which provides a high velocity jet of fluid to create suction in the gas chamber and entrain gas into the ejector. In the following mixing tube the liquid jet attaches itself to the tube wall resulting in a rapid dissipation of kinetic energy. This creates an intensive mixing zone or shock where the high turbulence produces a fine dispersion of bubbles with a large interfacial area for mass transfer.

Static mixers and gas–liquid ejectors are plug flow devices and this can improve selectivity for consecutive reaction schemes. Due to their very high energy dissipation rates they can increase the mass–transfer coefficient by an order of magnitude compared to stirred tanks. The large levels of turbulent energy dissipation produced in these high intensity mixers act to reduce the dispersion size, dramatically increasing the interfacial area, – typical gas bubble sizes range from 0.5 to 2.0 mm, compared to 1.0 to 5.0 mm in stirred tanks and bubble columns. These factors combined mean such devices have the very major benefit as reactors of mass transfer rates 10 –100 times those of a STR.A significant benefit of high intensity inline mixers is that they have no moving parts, therefore sealing, high pressure and hazardous materials are less of a problem. Static mixers can be used for single phase mixing, to create gas in liquid or liquid in liquid dispersions, and for multiphase process, including those involving solids. The following case study indicates the substantial impact such devices can have.

One U.S. company produces a key intermediate using a gas liquid reaction in a packed column. Poor gas dispersion was leading to local hot spots and the formation of a gel byproduct. This gel seriously reduced catalyst performance and forced the firm to shut down the process every 2 or 3 weeks. Productivity of the column was limited by gas flow rate: it became unstable above 600 lb/h. Faced with a projected increase in demand, the company either needed to increase productivity or spend $5 million capital in new plant.

It was identified that gas liquid mixing and mass transfer could be substantially improved by incorporating a static mixer upstream of the bed and changing the injection arrangements. The mixer was designed using data from the HILINE program. The results of a $20,000 retrofit were staggering. Intensification of the mixing led to an increase in productivity of 42%. Start up and shut down became much more robust. Gel formation was completely eliminated, so avoiding the need for shut downs. The process is still running well, over 3 years later: the additional $5 million capital spend has been avoided.

**Rotor–Stators**

A rotor–stator mixer is a device designed to mix and homogenize by passing liquid through a high–speed rotor that is spinning very close to a motionless stator. Its high energy dissipation rates make it suitable for disintegration, homogenization, solubilization, emulsification and dispersions duties. Any liquid or solid–liquid mixture passing through this small clearance is subjected to a milling action and then forced out through the stator experiencing intense mechanical and hydraulic shear. Rotor–stator mixers can be used as batch or in–line intensification devices. They can help reduce mixing times for liquids up to 1,000,000 cP. In liquid–liquid applications they can reduce droplet sizes below 1 micrometer – significantly increasing mass transfer rates.

These and other high intensity mixing devices have been investigated by the industrially funded HILINE consortia, operated by BHR Group. Generic mixing, mass transfer and reactor characterization information has been developed using a range of tools, at shared cost, and is developed into guidelines for the design and optimization of these devices for a range of applications. Similar research consortia specialize in a single device, such as Rotor Stators – through the High Shear Mixing Research Program initiated by Prof Richard Calabrese at the University of Maryland, USA. However, it is not enough to make a process go faster because chemical reactions are rarely thermoneutral. The increased heat fluxes produced can cause familiar problems, e.g. thermal runaway and product degradation. So efficient heat removal is also required to prevent temperature increases.

**Compact Heat Exchangers (CHEs)**

As their name suggests, they are characterized by their compactness, with heat transfer surface areas greater than 200 $m^2$ per $m^3$ volume, compared to 80 $m^2/m^3$ for a shell–and–tube exchanger with 1–in.–dia. tubes. When high area densities are combined with techniques for enhancing heat transfer coefficients, the resulting CHEs may be viewed as an intensified heat exchangers. The smaller temperature differences achievable between the process and cooling streams results in reduced fouling and lower energy requirements, even with channel dimensions of only millimeters.

There are many CHE designs, ranging from enhanced shell and tube to plate and frame and plate and fin designs. The printed circuit heat exchanger (PCHE) are manufactured through chemical etching to produce fluid channels, followed by diffusion bonding to make a very strong heat exchanger core. This production method allows a significant degree of flexibility in design and utilization.

Industries that have adopted CHEs include industrial gases for cryogenic separations, where capital and power savings are the main drivers, and the offshore oil industry where space, weight and mechanical integrity are key issues. CHEs are available in a range of materials of construction, ranging from carbon steel, through stainless steel to more exotic alloys such as Hastelloy, Inconel and Incoloy. Polymer film CHEs have been developed based on PEEK (polyetheretherketone) and polyimide. Although the thermal conductivity of polymer is relatively low, corrugated plates are formed where the thin films possible (ca. 100 micrometers thick), resulting in high heat transfer capabilities.

### Integrated Reactor–Heat Exchangers (HEX Reactors)

There is further advantage and elegance to intensifying fast exothermic or endothermic reactions by combining the reaction and heat transfer in a single item of reactor equipment. Such equipment includes static mixers fitted with cooling jackets, heat exchangers that are used as chemical reactors and cooled spinning disc reactors.

A well known example of the first of these is a nitration plant in the U.K. The mixed nitrating acids are injected at multiple locations along the axis of a shell and tube HEX reactor, containing mixing elements. The feed strategy allows the heat load to be staged, enabling isothermal reaction conditions to be approximated along the whole reactor. It is estimated that the intensified process is about 50% more profitable compared to the conventional process, mainly as a result of higher purity product and lower running costs.

With their high heat transfer capabilities CHEs are well suited as HEX reactors. They offer better process temperature control, providing improved selectivity and consistency between batches, and involve lower fluid inventories, giving improved safety and faster response to changes in process conditions. With new manufacturing techniques, such as diffusion bonding, it is possible to design the geometries of flow paths in CHEs to aid mixing and incorporate reactant addition within the process channels.

The diffusion bonding manufacturing technique makes it possible to combine the advantages of CHEs with the ability to perform reactions inside a heat exchanger. Performing mixing, reaction and heat transfer within a single unit could lead to very different chemical plants in the future. Using the PI approach of matching the fluid dynamic environment to the requirements of the chemical reactions, Marbond reactors tailored to a process can be produced. The reactor may be divided into zones such that separate process streams are cooled or pre–heated before being combined in a zone of intense mass and heat transfer. For sequencing of reactions in an industrial application it is possible to provide as many reagent injection points, temperature adjustment and reaction zones as required. BHR Group and Chart Marston were recently presented with the Process and Food Innovation Award 1999 for this technology by the Manufacturing Industry Achievement Award.

An extension of the opportunities afforded by CHEs is their use as catalytic reactors. Catalyst can be coated directly on to the heat transfer surface or packed into the reaction channels. In this way the superior heat transfer characteristics of the CHE minimize thermal gradients in the catalyst bed and allow better control of the reaction process.

### Higher mass transfer performance by centrifugal techniques

Process Intensification is often considered synonymous with the pioneering work by Colin Ramshaw at ICI in the early 1980s on "HiGee" separators capitalizing on centrifugal force. Performance of packed columns for countercurrent mass transfer (e.g. distillation) is limited by flooding of gas. Ramshaw recognized that flooding correlations incorporated a term in g, the imposed gravitational field. Raising g by factors of 100s or 1000s could drastically increase gas capacity and hence mass transfer performance. By incorporating suitable packing into a rotor, orders of magnitude reduction in plant scale can be achieved. Implementation of this technology has been hampered by a reluctance of engineers and operators to use rotating equipment because of mechanical reliability and sealing issues. However, as Ramshaw has stressed on many the engineering issues encountered in Higee are similar to those in centrifugal pumps and washing machines, so are readily soluble.

More recently interest in this technology has picked up. In the early 1990s, the "center of gravity" of work on HiGee moved from the U.K. towards the U.S., at Case Western Reserve University, and to China. In 1989 a well–funded institute for HiGee was set up at Beijing University of Chemical Technology. Many applications are under development, and a full–scale deaeration unit has been installed on a large, onshore oil field. It is now operating very successfully and reliably. Using rotating packed bed (RPB) technology, Dow has produced an economically viable process for the production of low–chlorides hypochlorous acid (HOCl), a task which had previously defeated conventional technology.

### Spinning Disk Reactors

A second technology based upon rotation is that of spinning disk reactors. When fluid is placed at the center of a rotating disk or bowl an intrinsically unstable, highly sheared liquid film is produced. The flow field associated with the ripple propagation, which can be increased by incorporation of grooves into the disk, is believed to be responsible for the very high heat and mass transfer intensity. The Process Intensification & Innovation Center at Newcastle have extended their studies of polystyrene and polyacrylics polymerizations on the spinning disk reactor to now include photo–initiated reactions. A single pass of reactants over the surface of the disk can be equivalent to up to 45 minutes in a conventional reactor. This technology can also be applied to reduce size and improve size distributions of crystals produced by crystallization, and is currently being evaluated by several drug and fine chemicals producers who are achieving improved selectivity and greater conversions.

**Oscillatory Flow Reactors**

For cases where a continuous reactor, minimizing back mixing, would offer advantage to an inherently slow process (traditionally requiring a long residence time reactor) one potential solution is the oscillatory flow reactor. These comprise tubes with a series of baffles (e.g. orifice plates). Oscillatory flow is induced on top of the main through flow, which promotes plug flow behavior, even for low flow rates and laminar flow. In one application for production of a moderate volume specialty chemical a $25m^3$ batch reactor, with batch time of 12 hours may be replaced with a $4.2m^3$ oscillatory flow reactor (with a residence time of 2 hours). Benefits include improved safety through volume reduction and reduction in formation of a byproduct.

**Other Technologies**

Further methods for intensifying transport processes can contribute to better processes. Sonic and ultrasonics can be an effective in enhancing mass (by 50%) and heat (by 100%) transfer at solid– liquid interfaces, by creating a periodic velocity component between the phases. The use of vibration of a solid electrode, described in the proceedings of a recent PI conference, led to a 27–fold enhancement of mass transfer.

**Future PI Technology – Micro Devices**

All of the technologies described to here are established, at least in their own niche, so the risks of using them as reactors are not great. Experience in their design and operation has been developed to allow their optimization. A technology which is currently in development, but fits under the PI umbrella, and which will at least have some specialist applications in the future is micro devices.

Micro devices have channels with dimensions of 10–6 – 10–4 m, orders of magnitude smaller than in CHEs and HEX reactors. Owing to their size, there is an often cited analogy between micro electronics and micro devices. Traditional chemical plant is said to be equivalent to main frame computers that occupied whole buildings 20 years ago while micro devices are equivalent to the "lab on a chip".

Static micromixers can produce mixtures of liquids and gases, as well as generate multiphase dispersions. Such devices, which can be manufactured using methods borrowed from the electronics industry, can have channels down to 10 micrometers. The mixing mechanism is based on flow multilamination with subsequent interdiffusion of molecules between the overlapping fluid lamellae. When used as a reactor the reduction of the diffusional path length results in enhanced mixing and mass and heat transfer.

As with HEX reactors scale–up of micro reactors simply involves manufacture of a larger number of micro channels – no change in scale of flow path and consequently no change in flow regime or mixing mechanism. Hence process dynamics are unchanged in moving from the laboratory to commercial production. Hence the buzz word, "scale–out" rather than scale–up. Benefits resulting from the small size and compactness of micro reactors expand on those of PI reactors, most significantly very small foot print, large surface area for catalyst surface–initiated reactions, easier control of reaction and flow and low cost.

Increased awareness of the potential of Process Intensification is the first step to overcoming resistance to its practice. On Site Process Intensification (OSPRI) is a U.K. based initiative to assist the chemical industry in adapting reactor technologies that are more tailored to pro–cess needs. The aim is to design and construct a mobile pilot plant which can be used by chemical companies to assess the potential of PI reactor technology at reduced cost. Through this project the demonstration of the operation of industrial process at semi production scale will lead to widespread adoption of the PI approach.

Also in the UK, the Process Intensification Network (PIN) has been established to bring together industry and academia, across a range of disciplines, to encourage innovation and creativity and to develop ideas for future support from funding bodies. The Network organizes regular meetings, publishes a Newsletter and will produce a PI Guide, and has a dedicated Web site (http://www.ncl.ac.uk/pin/). Links exist with a similar group in the Netherlands.

## PROCESS INSTRUMENTATION AND CONTROL

Advanced controls are rapidly becoming part of the chemical process industries (CPI) landscape. The attractions are increased process reliability and process yields, which impacts profitability. And when process equipment are well–controlled, they are subject to less stress, which results in longer life. At ACHEMA 2000 more than 600 exhibitors presented their latest developments in process instrumentation and control.

Additionally, walls are crashing down throughout the CPI as information technology bulldozes the data barriers that separate manufacturing from management. Once kept on "Post–it" notes, in bulging file folders and cabinets, or, more often, in the brains of individual engineer managers, sales representatives and shipping clerks, information is now being streamlined to be available when and where it is needed.

The worldwide market for such I&C systems is several billion DM. For example, the combined software and hardware markets for batch–control systems is about DM 4 billion and growing at 5.5–6% per year, according to Automation Research Corp. (Dedham, Mass.). The global market for comprehensive operator–training systems is approximately DM 330 million, with an expected industry growth of 18% average annual rate by 2002. Sale of licenses for Microsoft's newly introduced Windows CE, a real–time operating system for embedded devices, is estimated at 14 million by 2003.

ACHEMA exhibition and congress highlighted recent developments and topics in I&C. They range from vertical integration to self–validating systems, from operator train simulations to new standards for batch control.

Process–control developments more flexible and user friendly

The most significant new developments in process–control technology include:

– Fieldbus–based systems such as Profibus and Foundation Fieldbus

– Fieldbus–enabled sensors and actuators

– Control systems that offer standardized connections to business–management systems

– Asset–management systems

– Advanced process–control applications for smaller production units

– Software for the integration of horizontal activities, such as optimized supply–chain management

– The trend to component and system–centered business.

For the control–system user, open standards are becoming increasingly important because they ensure the interoperability of various bus systems and control elements. So–called de facto standards from the office area will also become more common, for example, the use of multimedia applications based on office applications.

As far as the current fieldbus war between Profibus and the Foundation Fieldbus, experts believe that if the systems do not become interoperable, or at least open to one another, they will be replaced by the next generation of products, which are already in development.

## Vertical integration from business planning to production

New standards for "middleware", the software linking control and business systems, as well as advances in object oriented programming, are driving the development of systems that allow data to be transferred directly from business planning to production. At the cutting edge of this "vertical integrations" trend are integrated control and information management systems (ICIMS), which connect maintenance, computer–aided drafting and design (CADD), electronic document management and plant information management data, in real time, with business systems such as enterprise resource planning (ERP). On a more–limited scale, more CPI firms are installing ERP systems and linking them with plant information systems.

## Advanced control

In any chemical–process plant, the manufacturing objectives are to maintain safe operation and produce products with the desired qualities at the desired rate and minimum operating costs. Every process licensor provides basic controls for operating the plant. However, many operators prefer to install controls that use state–of–the–art process modeling and algorithms.

The objectives of maintaining a high production rate and acceptable product quality are complicated by the need for frequent grade switches, and the inherent, related time lags. Ideally, any advanced control system for chemical manufacturing should be able to:

– Monitor reactor and downstream equipment conditions, and promptly react to undesired situations

– Estimate product quality from process–unit conditions and adjust these conditions, as required

– Keep product production at the desired value

– Facilitate switching between grades.

The control functions to meet these objectives focus on production rate, product quality, and control of transitions between grades.

## Production rate

This rate must be known before it can be controlled. Unfortunately, when the product is a solid or a slurry, simply measuring the amount of product is difficult. Often the production rate must be calculated from energy and material balances, rather than measured directly. Because of this problem, control is best accomplished using a multivariable, predictive, constraint controller (MPCC). The constraint–handling characteristics of an MPCC keep production at its maximum, while always keeping the plant in a suitable operating range.

## Product quality

Chemical quality is ordinarily tracked in the plant by off–line measurements at infrequent intervals. This produces substantial delays between sampling and analysis results. In conventional plants, where product quality is manually controlled by operators, these delays can lead to substantial quality variations. Advanced control not only eliminates that problem, but also offers capabilities that in themselves can make the operation more stable. Based on the estimated product properties, an MPCC manipulates the reactor and downstream equipment conditions to maintain the desired product–quality values.

**Transition control**

At the start of any grade switch, the operator selects a new recipe. Without advanced control, each transition to new operating conditions would require a series of steps that the operator follows manually. But with advanced grade–switching control, whenever production personnel select a new master recipe, the system selectively calls up the appropriate sub–recipes and transition instructions for different sections of the plant. The operators can modify some of the target parameters prior to switching the new recipe into service. Once the recipe has been approved by the operators, the transition is automatically controlled.

Transition control is an attractive candidate for more–sophisticated multivariable control using non–linear, dynamic models. Prototype systems using this approach have been developed by several companies, and are currently undergoing field testing. Initial results are showing promise, so further developments with more applications can be expected over the next few years.

**Self validating processes**

Imagine process operations that run as smoothly as an automobile with a computer–controlled engine. Such vehicle systems analyze signals from the engine, perform "self tests" and keep the engine running, even when signals jump out of the norm.

The vision behind validation for industry processes is to offer the same benefits, so plant availability can be increased. And, researchers of advanced instrumentation at Oxford University (Oxford, England), expect to see such self–validating sensor systems in industrial uses in the next two or three years.

However, applying the theory to industrial processes rather then car engines is trickier because no two processes are likely to be the same. Considerable thought must go into designing industrial validation to obtain economies of scale.

Creating cost–effective self–validation (SEVA) that detects faults and keeps a process operating when signals go awry begins with instrumentation. According to the Oxford researchers, faulty sensors cause about 60% of plant shutdowns, while faulty actuators cause around 30%. With validated systems, a faulty sensor or actuator doesn't have to shut down a process.

Sensors with built–in fault detection are already on the market. The remaining challenge is to tie them into overall validation systems that ensure the safety, maintainability and availability of modern industrial plants.

To do that, data from the sensor needs to be reported in a generic fashion. That way it can be used at destinations ranging from control loops to maintenance crews, accounting and process management. In addition, both instrument and control systems for industrial processes should have a "limp–home" operation.

For cars, this means that the computer–controlled engine detects faulty performance, signals the problem, and substitutes the faulty data point with a best guess. The engine continues to operate, though at a lower efficiency, and the driver can still easily get the vehicle to a service center. For industrial processes, a SEVA sensor system enables a process to operate at a lower efficiency, but still safely. Of course, not all processes can use a "limp–home" strategy. For instance, safety–critical processes would shut down at the detection of a fault. But for appropriate processes, validation would allow maintenance crews to arrive for "just–in–time" repair, which increases plant availability.

For industrial validation, the duty of the sensor is to provide a best estimate of the process parameter even in the presence of faults. For example, a temperature sensor would store historical temperatures that it has measured during its operation. When a fault is detected, the sensor calculates a best guess for the actual temperature by using its store of temperature data and an algorithm. As the process continues to operate, the substitute value is smoothly ramped to an average temperature, again based on historical data.

Along with the best guess, validated sensor systems will indicate the reliability of the calculated guess by means of and uncertainty level. A SEVA instrument should at all times generate validated uncertainty, which is updated to reflect operation conditions and, in particular, to quantify the effect of faults.

**Mobile controls**

Windows CE, a 32–bit operating system by Microsoft Corp. (Redmond, Wash.), brings the power and flexibility of personal–computer (PC) software programs to the applications level, including human–machine interfaces (HMI). Windows CE is already used in personal palm–size PCs, but has some significant competitors in the consumer market, but in the industrial–automation arena, Microsoft has a clear lead.

Windows CE has three main attractions. First is its lineage: like Windows NT, CE is based on a subset of the Win32 application programming interface (API). This gives software developers access to more than four million Win32 programmers. It also helps cut costs and development time by allowing programmers to produce families of linked products.

For companies that don't need the power of – or don't want to pay for – Windows NT, the Windows CE is an alternative. A license for Windows NT can cost three to ten times that of Windows CE. And CE is also carving a niche in harsh environments. Unlike other OSs (including Windows NT), Windows CE operates from a microchip rather than a hard disk. This eliminates the need for fragile disk drives.

Many companies have or will have Windows CE 3.0 –based product lines. For example, a multifunctional platform already on the market combines operator interface with a soft programmable logic controller (PLC). Some companies have demonstrated their ability to port their HMIs to handheld devices running on Windows CE.

These tools are not meant to replace conventional HMIs or desktop terminals. Rather, they are designed to enhance the efficiency of users, such as maintenance personnel, who can view the condition of processes and equipment while moving about the plant.

Another company has released a CE–based suite of tools for object linking and embedding (OLE) for process control (OPC) compliant application for plant automation. According to the firm, this suite is the first to include DCOM capability for Windows.

Going one step further, a provider of computerized maintenance–management systems (CMMS), is using Windows CE in a product that allows maintenance engineers remote access to the company's client–server network that requires conventional user to sit down in front of a computer to access information. Remote users can download pending work assignments via a docking cradle, or via dial–up or wireless connections.

### Training simulations

Knowing what to do in case of plant emergencies is one of the basic know–hows that plant operators should have ingrained in their memory. However, as processes become more automated, operators are getting less and less exposure to such conditions.

As a result, the demand for training packages is still on an upward trend. Companies are continually updating their training packages. The chemical process industries are finding that training in a virtual plant via operator–training simulators is effective in offsetting inexperience in handling upset conditions. Many companies now entering the market have traditionally been known for process–simulation software. The next step in operator–training simulation is to develop virtual reality applications.

### New standards for batch control

In the batch–processing automation market, standards are paving the way to improved product quality, faster product–development cycles and reduced production costs. Applications specialists have seen projects save as much as 40% in implementation costs. Customers note an average of 10–20% saving in batch–cycle time. Most of these savings come from the greater repeatability offered by automated batch control. As a result, the batch market is growing steadily.

The first significant batch–control standard was S88.01 (Batch Control Part 1: Models and Terminology), from the International Society of Measurement and Control. Since its issue in 1995, S88.01 has helped to make the pieces of a batch–control system more modular.

Now that S88.01 is firmly in place, the next set of related standards is almost ready for release. Expected to be issued this year, S88.02 describes how data needed for batch control can be stored and exchanged.

S88.02 consists of three parts: data model, data–exchange tables, and procedure and recipe representations. The data model is the formal representation of the key concepts described in S88.01, such as recipe entities and equipment entities. They are based on the universal–modeling language (UML) object–modeling notation. The data–exchange tables, which will enable systems from different vendors to interoperate, use the database query language SQL.

SP88 uses a combination of list formats, Gantt charts and a sequential–function chart (SFC). Most companies have been following the International Electrotechnical Commission's (IEC; Geneva) standard, IEC–61131–3, which uses a SFC. By standardizing on PFCs, the SP88 committee hopes to reduce the learning curve between control systems by allowing users to easily visualize the relationships between unit procedures.

SP95 is another new standard for integrating control systems with business systems, such as manufacturing execution systems (MESs). It will help to define a common language and understanding for two groups – information technology and process control – that have traditionally been separate. The standard is expected to break down the barriers of language and terminology, thus eliminating islands of information. This will be the first step toward "plug–and–play" applications, where the seamless "single" system will become a reality.

## PROCESS SAFETY

For engineers throughout the global chemical process industries, process safety is a never–ending pursuit. The main drivers for improved process safety are the need to protect human life while meeting corporate, public and regulatory pressures for cleaner, safer plants, and the desire to improve operability while protecting capital equipment and other plant assets.

Process safety is a serious matter. Between 1987 and 1996, 605,000 chemical–plant safety incidents occurred in the U.S. alone, with 10,000 of them causing injury or death, according to information complied by five government–agency databases (Chem. Eng., July 1999, pp. 97–98).

While it is difficult to establish a direct causal relationship between worker downsizing and safety, record–setting merger & acquisition (M&A) activity in recent years, and the resulting layoffs, poses special challenges where plant safety is concerned. As staffs are downsized, workloads increase and the scope of job responsibilities widen, causing staff loyalty and morale to suffer. Over the long term, these intangibles can have a real impact on plant safety.

Similarly, companies that buy older facilities often struggle to manage these new acquisitions safely, particularly when no strong historical safety program exists onsite. Where contract workers are called upon to fill resulting voids, plant operators must take extra care in choosing qualified contractors and closely managing – and auditing – their work.

**Regulatory mandates**

Principles of process–safety management are well–established in most countries, many of which have some form of process–safety regulation. In the U.S., chemical process operators are governed by the 1992 Process Safety Management (PSM) Rule from the Occupational Safety and Health Administration (OSHA; Washington, D.C.), and the 1996 Risk Management Plan (RMP) Rule from the Environmental Protection Agency (EPA; Washington, D.C.). Regardless of the specific regulatory drivers, the development of a sound process–safety management plan requires ongoing effort to improve operating procedures, conduct process–hazard analysis, and ensure the mechanical integrity of equipment.

**Inherent safety – A pipe dream?**

Engineering organizations that are able to implement a sound process–safety strategy often enjoy a demonstrable return on investment, by minimizing accidents and injuries, reducing unscheduled downtime, protecting plant assets, and even lowering insurance premiums and regulatory penalties.

The holy grail for process operators, plant engineers and loss–prevention specialists is to design and operate so–called "inherently safe" facilities. In general, when designing a process, engineers first identify the core design, which is defined by chemistry, heat and material balances, and basic process controls. Once the core design has been determined, engineers then examine ways in which all systems could break down. They look at issues that could impact the reliability, safety, quality control and environmental impact of the process or system. By determining what types of failures might occur, engineers are then able to improve the design or implement engineering controls to minimize the likelihood of such mishaps.

To evaluate a process for inherent safety, engineers typically assess the following factors:

– Material properties such as the quantity, flammability, calorific value and reactivity of flammable or unstable substances

– The presence of endothermic versus exothermic chemical reactions

– Issues related to materials handling or transfer

– The use of sub–atmospheric pressures and extremely low temperatures

– Operations at or near the flammable range

– Operations that may increase the risk of a dust explosion

– The need for and proper use of pressure–relief devices

– The potential for corrosion or erosion of pipes, vessels and connections

– Leakage of joints and packings

– The use of fired equipment, rotating equipment

Ideally, safety should be a theme at each state in a systematic design cycle – laboratory, pilot, production design, and operations. The most cost–effective solutions tend to emerge in the earliest design stages.

To help plant engineers quantify the inherent safety of a process and identify those that could use some extra attention, Dow Chemical Co. (Midland, Mich.) has developed the Fire & Explosion Index (F&EI). It has evolved over 25 years, as a semi–quantitative measure of risk from processes handling flammable and explosive chemicals, and provides a comparative measure of the overall risk of fire and explosion of a process. This index is designed as a practical tool for measuring the inherent safety of a design, and for assessing whether process changes are improving things or making them worse. Plant operators can use F&EI results to justify making process changes and engineering improvements to boost plant safety, particularly in process units that demonstrate a relatively high potential for toxic releases or reactive–chemical incidents.

**Software tools can help**

Software–based tools are also available to help engineers in the pursuit of greater process safety. These include interactive training programs that include simulated scenarios, animated models and narrated guidance, and database programs to help operators maintain up–to–date versions of regulations, operating procedures, and training manuals.

Similarly, to manage all safety–related information better, some facilities are developing centralized databases that integrate all relevant information and data related to environmental health and safety. The goal is to organize and centralize all information that could cut response time and potentially save lives in the event of a plant emergency. Such efforts typically involve designing a centralized database to house such critical information as plant operating procedures, material safety data sheets (MSDSs) for all chemicals handled or manufactured onsite, and extensive emergency–response actions.

To further capitalize on improved data management, many chemical process facilities going one step further, integrating their regulatory–compliance and safety–related databases with other value–added tools in their computer arsenals – namely enterprise–resource planning systems, electronic–document management systems, and computerized maintenance–management systems.

Fire safety is an important component of any process–safety–management program. In the U.S., fire–safety regulations are mandated by the U.S. Occupational Safety and Health Admin. (OSHA; Washington, D.C.). Other important fire–related industry guidelines have been developed by AIChE's Center for Chemical Process Safety (New York, N.Y.), the European Process Safety Center (Rugby, U.K.)., and the National Fire Protection Assn. (NFPA; Quincy, Mass.). Guidelines and standards from these organizations address such chemical–process topics as handling and storing flammable and combustible liquids, cutting and welding, venting of deflagrations, explosion prevention and static electricity.

**The impact of process–safety rules**

In the U.S., OSHA's PSM standard was mandated in February 1992, while EPA's RMP Rule was published in its final form in June 1996. The 17th edition of J&H Marsh and McLennan's "Large Property Damage Losses in the Hydrocarbon–Chemical Industries: A Thirty–year Review", issued in 1997, reports that a near–40% decrease in the number of losses (i.e., property damage, cleanup, employee injuries and fatalities, and liability claims) was recorded in the U.S. chemical and hydrocarbon segments between 1992 and 1996 (Chem. Eng., May 1999, pp. 114–121). The insurance giant Marsh & McLennan notes that between 1987 and 1991 – prior to the implementation of the PSM and RMP Rules – the number of losses in the CPI reached an all–time high of $2,83 billion, partly as a result of attempts to boost plant capacity, and the increase in large, single–train operations, which result in greater concentration of people and plant assets in a more–concentrated area.

However, between 1992 and 1996, the losses in the hydrocarbon and chemical segments dropped to $1.48 billion, due in part to efforts undertaken to upgrade sites and improve safety management and worker training, as part of overall compliance with with OSHA's PSM Rule and EPA's RMP Rule.

According to Marsh & McLennan's assessment, vapor–cloud explosions account for 36% ($111 million) of the chemical and refining sector's losses, with explosions (29%; $61 million) and fires (31%; $55 million) for second and third place. The most frequent cause of loss results from mechanical failure of equipment (with 43% of the losses, valued at $72.1 million). Failure of piping systems account for 33% of the losses, costing $77 million. Reactor–related incidents, which placed third at 10% of the losses, cost the most ($152 million). Tanks (15%; $62 million) and process towers (8%; $87 million) were runners–up in this category. Second to mechanical failure of equipment, human error was blame in 21% of the loss incidents, which cost these sectors $87.4 million.

**Gather data and improve operations**

As is so often the case, improved process–safety–management initiatives must compete with other initiatives for scarce corporate resources. To help justify process–safety–related expenditures and efforts, process operators should gather as much safety–related data as possible, and analyze it. For instance, by collecting and analyzing operating and incident data, proactive process facilities can not only determine plant–specific incident rates, but can improve plant safety performance over time, and make intelligent comparisons between similar plants (a methodology is described in Chem. Eng., August 1999, pp. 86–88). Such performance trending can help the engineer evaluate the effects of changes in plant operating practices, procedures and programs. And, comparisons between plants can highlight the comparative effectiveness of different plant designs, operating programs, training methods and even plant cultures.

With sound data management and performance measurement, decisions can be made about how best to spend scarce funds and focus efforts at future improvements. Conversely, identifying performance trending in the wrong direction allows management to improve efforts before a serious incident or accident occurs.

**PLANT ENGINEERING TOOLS**

Long before any land is cleared, concrete poured or metal delivered, a new plant is a bunch of paper. Process flow diagrams (PFDs), plot plans, piping and instrumentation diagrams (P&IDs), equipment lists and cost estimates are generated during front–end engineering and design (FEED). These documents convey the bare–bones plant design that goes out for bid and gets refined, but not dramatically altered, during detailed engineering. At ACHEMA 2000 numerous enterprises presented their latest developments for plant engineering.

However, by stipulating one design rather than another, FEED documents are said to determine 80% of the total installed cost of a plant. Every decision made during FEED ripples through and can have a big impact all the way through operating the plant.

With so much hinging on decisions made in the first phase of the plant life cycle, engineers are turning to new software tools to improve the FEED process. As a result, the global market for engineering design software is estimated at $1.8 billion in 2000 (U.S. market analysts).

The integrated programs churn out the diagrams and paperwork so fast and effectively, process engineers can now look at a slew of possible designs, then choose the most cost effective option. The concept is to do more evaluation up front, to consider more alternatives, and to basically find a cheaper solution" says Rick Carell, accounts manager at Rebis Industrial Working Software.

"Technology packages that would have taken 23 weeks to do a few years ago can be put together in about 14 weeks now," says Tim Challand, manager of project definition for Kellogg Brown and Root, Inc. "But to some degree it isn't comparing apples with apples. Today we do a lot more–we look at more cases, more feedstocks, and more complex process control systems."

As a result, optimizing FEED can save an estimated 30% of capital costs over the plant life cycle, according several engineering software vendors. Honing plant design from the get–go eliminates the 40% overdesign traditionally built into a facility.

"Owners don't have to pay for the overdesign," says John Newsome, manager of the hydrocarbon business group at Shell International Oil Products B. V. But losing the flexibility inherent in that excess, Newsome says "is sometimes a disappointment to clients."

Like having the right tool for the job, FEED packages consist of different programs designed to do the various tasks needed for process conceptualization and basic engineering. They are often simplified versions of heavy weight tools that have been used in detailed design for years.

The suite of programs share a common database, so critical engineering information is quickly integrated into the overall design. One program crunches through calculations for material and heat balances, using that information another program simulates the process, a third takes process specifications and develops a PFD. Still others render rough plot layouts, P&IDs or calculate costs, maybe even a three–dimensional image of the plant.

### Customized design packages integrate company's own know–how

A FEED toolkit can be customized to accommodate a company's own engineering know–how as well as containing a variety of commercial software that meet specific design needs. Often a company will develop in–house a central engineering database to manage the engineering data. With the integrated applications and management systems, cost and facility data can evolve progressively and smoothly from process conceptualization through plant startup.

For example, the FEED toolkit of Stork Comprimo België N.V. (Antwerp, Belgium) contains PRO II by Simulation Sciences, Inc. and related programs such as In–Plant and Hextran for flowsheeting techniques; HTRI to solve heat transfer problems, and Icarus by Icarus International, Inc., for cost estimation. To manage the data, Stork developed Engineering Management Systems, or EMS, its in–house multidisciplinary engineering database that enables "one time entry" of data.

Similarly, Toyo Engineering Corporation (Tokyo) uses AutoPlant by Rebis for flow diagramming, PlantBuilder and AutoRouter by Design Power, Inc. for 3–dimensional layouts and routing. Toyo's FEED toolkit reduces the total design time by 10 – 20%, says Youichi Nishi, head of Toyo's integrated plant design group.

Bechtel Group Inc bolsters its third–party tools with its own proprietary technologies for ethylene and lube oil, for example, and three software programs developed in–house. Comet produces a simplified 3–dimensional CAD model for purposes of optimizing plant arrangement and producing quantity estimates. Project Works enables data flow and data management among all proprietary and third–party applications, and Bechtel Global Knowledge Network links the company's offices worldwide.

Years of experience has taught engineers at Fluor Daniel, that complex piping can often account for as much as one–third of a project's cost. Fluor partnered with Design Power, Inc., to develop an application that captures the knowledge of its most–experienced piping and plant design experts and applies it to new project designs. The result of the collaboration is the software tool, OptimEyes. This tool makes it possible to review multiple scenarios for equipment and piping placement and identify the most cost–effective plant layout. OptimEyes can produce accurate material take–offs (MTOs) and create three–dimensional (3–D) models.

The company's design work on a grassroots refinery project is a good example of the benefits of such engineering software. The $2–billion plant includes nine process units, plus offsite tankage facilities, requiring a total of more than 4,500 pipelines. The OptimEyes 3–D model enabled the entire team to visualize the complex design concepts for reviews and constructability evaluations and to react quickly to the changes that were identified in model and constructability reviews, says project director Brian Tomlinson.

The software includes an automatic transposition routing feature so that when equipment is relocated the piping is automatically rerouted. It also automates the production of MTOs by line class, pipe size and unit, which proved helpful in the preparation of the detailed estimate.

A further demonstration of the value of the software tool on the project occurred when the licensor for one of the specific process units provided a suggested layout. Fluor Daniel engineers developed a preliminary model of the unit according to the licensor's specifications and then, using the rapid routing capabilities of OptimEyes, created a completely new model. When they compared MTOs from both models, they found that the OptimEyes design saved more than $1 million in total installed cost for piping.

Using OptimEyes, we can prepare feasibility studies, proposals, and front–end engineering activities in a fraction of the time that it used to take when all of the drawings were created manually. For instance, Fluor Daniel has been able to prepare a feasibility study, using process–simulation data as a basis, in only 12 hours

Commercial data management software that integrate various programs are also becoming available. In January 2000, AEA Technology introduced Axsys, a database manager that integrates AEAT's own Hysys simulation program with a PFD and P&ID drafting tool and datasheets using standard packages such as Microsoft Excel.

According to Mitsubishi Chemical Corporation (Tokyo) reported Axsys almost halved the time needed to develop process licenses, mainly because data is entered only once, saving not only time but avoiding typing errors during multiple data entry.

In the next few months, Aspen Technology will introduce the 10.2 version of Zyqad, which integrates with SmartPlant P&ID by Intergraph. The compatible duo is the first of a series of integrated software, dubbed SmartSolutions for FEED, that the two companies have partnered to produce. Integrated versions of software for equipment data sheets and electrical schematics are scheduled to be marketed in 2000. Also integrated in the suite are links to Icarus ad Marian, the material managements package by Debis Systemhaus.

**Coming to the rescue**

By enabling engineers to run through multiple options and squeeze out the most economical design, the new FEED software can breathe life into projects that would not have gotten the green light.

For example, the company used its Foster Wheeler Design Assist (FWDA), a FEED package for pharmaceutical products, in a recent process expansion. Another engineering company assessed the total install cost at $40 million, which the pharmaceutical company red–lighted. Using FWDA, Foster Wheeler found a bottleneck not in the reactor and support areas as suspected, but in the primary utilities. The reactor modules will undergo a minor upgrade and the utility system will get a major revamp, all for a cost of $17 million. After using FWDA in–house for several months, Foster Wheeler started marketing it last year. The company recently began sublicensing the package to owner–operators so they can debottleneck daily operations.

By purchasing the "intelligent" documents and software package resulting from the detailed design and using them to fine–tune and debottleneck the plant throughout its operative life, owner–operators can expand their savings further.

The biggest saving of all comes when the owner–operator takes the information from expert design software system and maintains the unit. One client estimates that by using the design software for operations, the plant will save the equivalent of 23% of the building cost over its lifetime. Turning intelligent design documents and software over to owner–operators is something about 10 – 15% of clients want. Another 40 –50% of the clients want just the electronic documents. Along with E.I. du Pont de Nemours (Wilmington, Del.) and Merck and Co., Inc. (Whitehouse Station, N.J.), Kvaerner has developed FEED and detailed engineering packages–Vantage, a CAD and engineering database, and Focus, a project manager used in conjunction with 3D system PDMS–that are now licensed through Cadcentre Group plc.

According to the press informations
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